DETECTION OF COMPOSITE DELAMINATIONS AND BROKEN SOLDER JOINTS BY A FULL-FIELD LASER DOPPLER TECHNIQUE

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INTRODUCTION

A method for full-field non-contact vibration measurement based on the Michelson Interferometer has been developed and applied to a wide range of components and structures. Unlike other optical techniques such as holography, the vibration imager does not require a specialized laboratory and stable environment, works over a much wider dynamic range,and the vibration time history is available for a more detailed analysis of the structures response. Use of this technique to detect delaminations in graphite/epoxy specimens is explored in this paper. The data was compared with X-ray and ultrasonic methods. The integrity of solder joints in electronic circuit boards has also been studied by this method at the University of Wisconsin, Madison and is also presented in this paper.

PRINCIPLES OF OPERATION

The vibration imager, developed by Ometron [1], from work conducted by L. E. Drain and B. C. Moss at the Materials Physics and Metallurgy Division of the Atomic Energy Research Establishment (AERE) Harwell, England [2], is shown schematically in Figure 1. It is based on the Michelson Interferometer in which a coherent light beam is divided into two, the signal and the reference beams which are then recombined. These two beams constructively or destructively interfere with one another depending upon the difference between their optical path lengths. The light beam is produced by a 10 mW Helium Neon laser.

The direction of the surface is determined by a two phase optical detection system. After recombination, the reference and signal components are coded by polarization. The two phases are used to single side band modulate a carrier frequency generating the sum or difference frequency of the signal and carrier. The signal is therefore frequency shifted to allow us to obtain directional information.

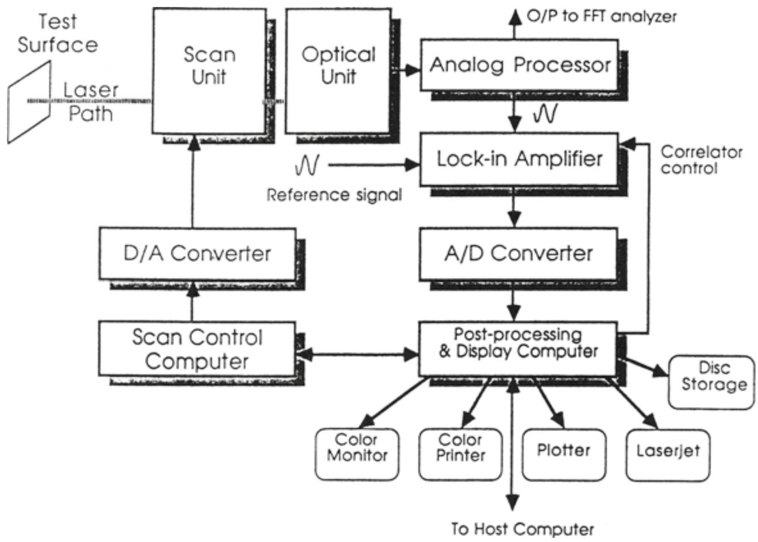

Figure 1. Schematic of the Vibration Imager

The Analog Processor converts this frequency modulated doppler signal into a velocity signal which passes directly into the Lock-in Amplifier. An electronic reference signal is taken from the waveform driving the test part under vibration or from a strain gage, accelerometer or other transducer attached to the part itself. This reference signal at the vibration frequency is correlated with the velocity signal by the Lock-in Amplifier. This is done in order to measure phase as well as amplitude of vibration and to desensitize the instrument to uncorrelated vibrations. The Lock-in Amplifier produces an output from which can be determined the RMS of the velocity signal.

DELAMINATIONS IN COMPOSITES

Experiments and Results

The specimens used in this investigation were fabricated with AS/3501 graphite epoxy tape. Two laminates were cut from the same 42-ply plate with a diamond abrasive saw such that their stacking sequences were

Type A:
$(0,90,45,90,-22.5,\pm 67.5,22.5,0,90,\pm 22.5,\pm 67.5,22.5,67.5,-22.5,-67.5,-45,-45,-22.5)_s$

Type B:

$(90,0,-45,0,67.5,-22.5,22.5,-67.5,90,0,-67.5,67.5,-22.5,22.5,-67.5,-22.5,67.5,22.5,45,45,67.5)_s$

The cross-section of the specimens was 1.5 inches x 0.20 inches and their length was 6.25 inches. Two notched configurations were used: a center-notch (CN) made from Type A, and double-edge-notch (DEN) made from Type B. These are shown schematically in Figures 2(a) and 2(b) respectively.

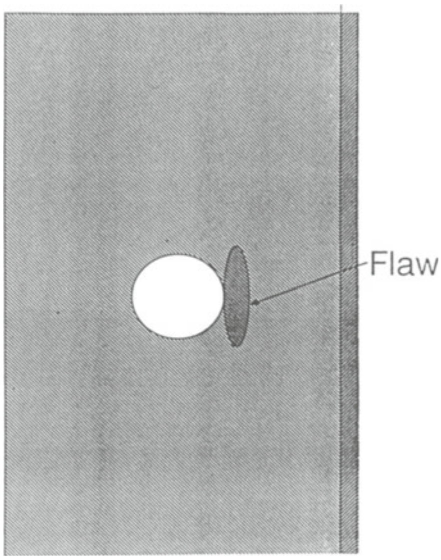

Figure 2(a). CN Delaminated Gr/Ep Composite.

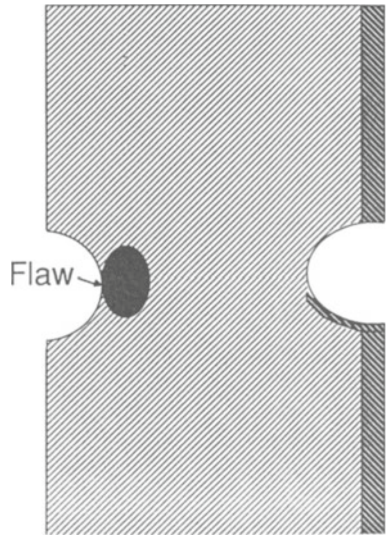

Figure 2(b). DEN Delaminated Gr/Ep Composite.

After fixing the specimens in a servo-hydraulic testing machine, a 10 Hz, fully reversed (R=-1), sinusoidal load was applied at constant load amplitude to ensue extensive fatigue damage. Mechanical testing was halted when laminate failure, as indicated by stiffness measurements, was approached. The extent of the damage growth was nondestructively evaluated with ultrasonic C-scans and penetrant-enhanced X-ray radiographs in the manner explained in [3].

Fatigue damage detected with the radiographs and C-scans consisted of matrix cracks and delaminations emanating from the highly stressed areas near the notch(es). From the radiographs, damage was indicated by dark lines (matrix cracks) and dark areas (delaminations) resulting from the absorption of X-rays by the liquid penetrant within the damaged material. These radiographs are shown in Figures 3(a) and 3(b). (In Figure 3(a), the large, dark, rectangular areas symmetrically located above and below the center-notch resulted from the V-notched aluminum tabs bonded to the specimen to serve as a firm seat for the extensometer's knife edges.) Areas of relatively high damage density also attenuated the ultrasonic C-scan signal, resulting in correspondingly lighter shades of grey as shown in Figures 4(a) and 4(b). Damage indications seen with radiography and C-scan represent an integration of damage through the thickness of the specimen. That is, damage at any location through the thickness is superposed to achieve the new effect seen in the figures.

After the C-scans and radiographs were performed, the specimens were loaded cyclically from 0-3000 pounds in compression at 15 Hz and scanned using the vibration imager.

The small delaminations adjacent to the notch in the CN specimen were located on the first five or six interfaces of the laminate. Under compressive loading, the sublaminates resulting from the delaminations buckle outward from the remainder of the laminate. This out of plane motion was detected with the vibration imager and the scan result is shown in Figure 5(a). A contour plot of this scan is detailed in Figure 5(b). The larger delaminations growing inward from

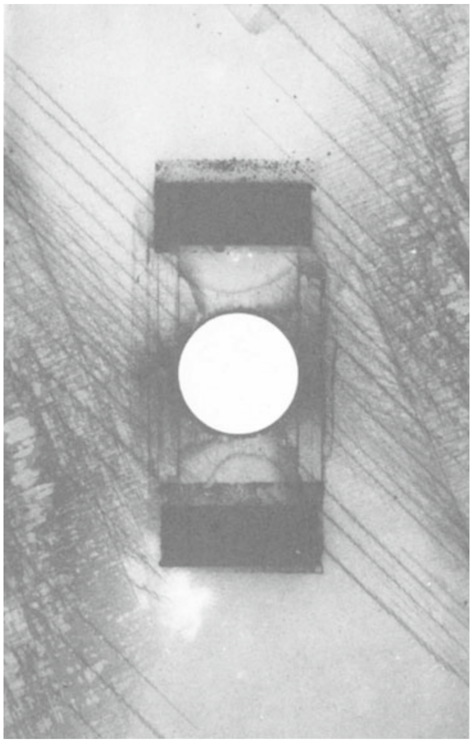

Figure 3(a). X-ray radiograph of the CN specimen.

Figure 3(b). X-ray radiograph of the DEN specimen.

Figure 4(a). C-Scan of the CN specimen.

Figure 4(b). C-scan of the DEN specimen.

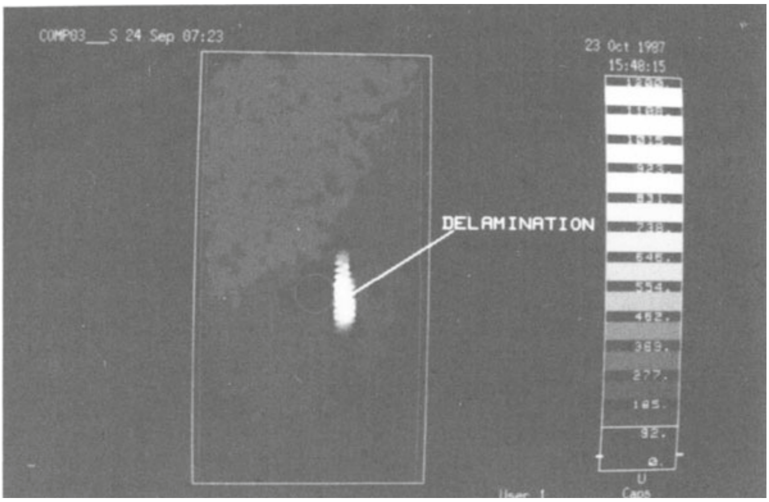

Figure 5(a). Vibration Image of the CN specimen. Load 0-3000 lbs in compression at 15 Hz.

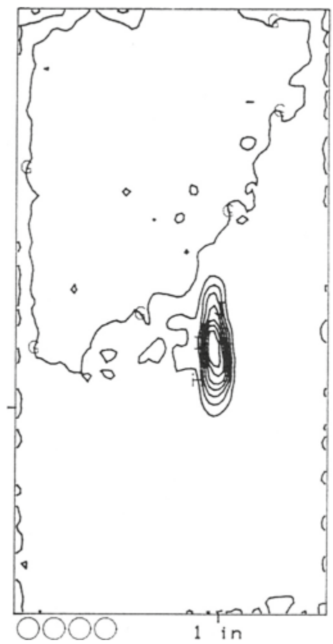

Figure 5(b). Contour plot of above image. Scale to the right indicates vibration in uncalibrated units.

the straight edges of the specimens (above the hole on the right side and below the hole on the left side) were located at the 15th interface from each surface, and were not detected by the vibration imager. These large straight-edge delaminations occurred close to the end of the fatigue test and were precursors to laminate failure. Only one vibration frequency was applied. One possibility in that by tuning to different frequencies, different features of the delaminations will be revealed. Application of broad band loading and modal analysis methods may lead to time savings and further information.

In the DEN specimen, a large delamination growing toward the center of the specimen from the left notch was located at the seventh and eighth interfaces from the back surface of the specimen, and, therefore, was not seen with the vibration imager. However, a smaller delamination at the left notch on the front side of the specimen did appear on the scan, which is detailed in Figure 6.

CONCLUSION

Although X-ray radiographs provide the greatest resolution of physical details, they give no indication of the effect of damage on the deformation of the material. The effectiveness of radiography is also limited by the ability of the penetrant enhancing agent to reach the damage. C-scans have less resolution of details than the radiographs but can detect damage without connectivity to the surface because they do not rely on a penetrant enhancing agent. Like the radiographs, a C-scan provides no information regarding the effect of damage on the deformation of the material.

Figure 6. A vibration image contour plot of the DEN specimen. Load is 0-3000 lbs compression at 15 Hz. Scale to the right is vibration in uncalibrated units.

The non-contact vibration imager is easier to apply than the above two methods and proved to be extremely sensitive to out-of-plane deformations associated with delaminations near the surface of observation. Compressive loads applied to the specimen aided in obtaining out-of-plane deformations due to the local buckling of delaminations. Delaminations occurring deeper within the composite were not detected. However, this does not imply that they cannot be detected. These experiments were preliminary, and until more experiments are performed, such as broad band random excitation, the extent of the vibration imager's application to delamination detection in composites cannot be surmised.

BROKEN SOLDER JOINTS IN ELECTRONIC CIRCUIT BOARDS

Experiment and Results

Figure 7(a) shows a schematic of the copper model of an electronic chip which was approximately 2 inches x 1 inch and soldered in ten places to a larger plate of copper, which represented a circuit board. The plate was gripped top and bottom and pulled cyclically in tension. The lower left hand solder joint was then manually cut. A scan was taken before and after the joint was broken. The dramatic difference of the two scans is emphasized in Figure 7(b), which is a display of the result when the scan data set taken after the joint was broken is subtracted from the scan data set before the joint was broken. Note the contours appear to focus on the broken solder joint. The experiment was successfully repeated on real circuit boards attached to a shaker.

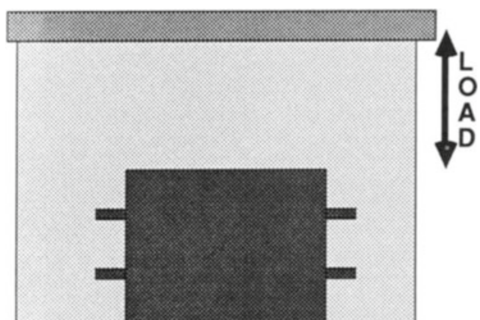

Figure 7(a). Schematic of the copper model chip.

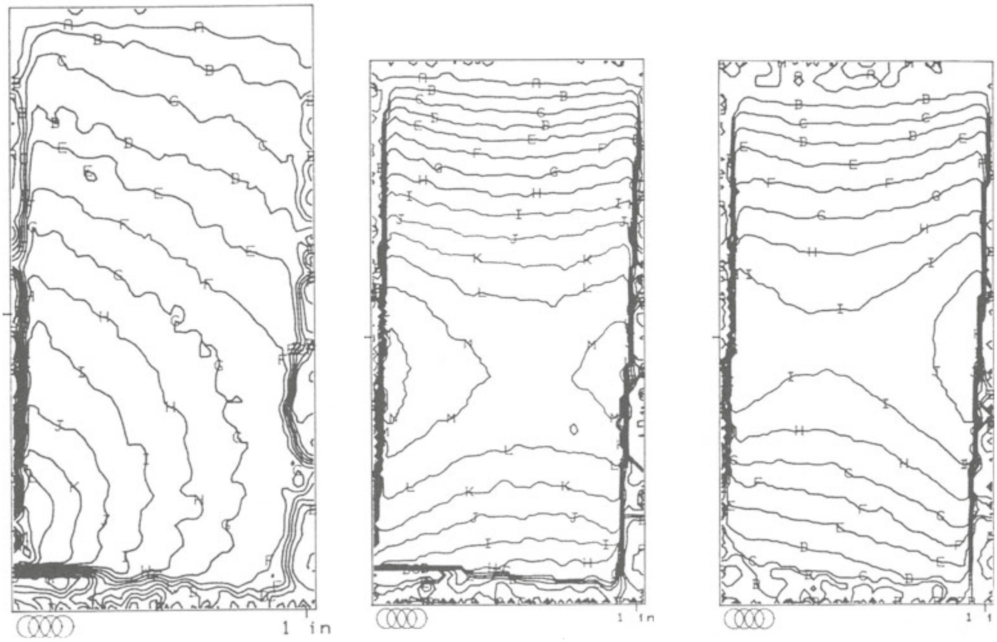

Figure 7(b). Highlights difference between scan data sets taken before and after solder joint was broken. Scale to the right indicates vibration in uncalibrated units.

CONCLUSION

The experiments indicate the potential for a rapid quality control inspection tool based on vibration imager techniques. Although area scans were performed, a single measurement adjacent to each joint may be all that is necessary. Measurements can be made at up to 50 points per second at present. Since data are digitized, stored, and available for post-processing, results could be statistically compared with a range of results from joints known to be intact.

ACKNOWLEDGMENT

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